Performance Analysis and Intelligent Power Controller Design of Soft Switched Half Bridge dc/dc Converter using Neural Networks

Mukhtiar Ahmed Mahar
Department of Electrical Engineering
Mehran University of Engineering & Technology Jamshoro Sindh 76062, Pakistans

Abdul Sattar Larik
Department of Electrical Engineering
Mehran University of Engineering & Technology
Jamshoro Sindh 76062, Pakistan E-mail

Mohammad Rafiq Abro
Ex-Professor
Department of Electrical Engineering
Mehran University of Engineering & Technology
Jamshoro Pakistan

Mohammad Aslam Uqaili
Department of Electrical Engineering
Mehran University of Engineering & Technology
Jamshoro Sindh 76062, Pakistan

ABSTRACT

During the last few decades several new dc-dc converter topologies have been emerged. These topologies are variable structure systems and contain nonlinearities which lead to oscillations during operation. Various conventional control techniques have been investigated and analyzed in order to minimize oscillations during the operation of the converters, in particular, under non-linear situations. However, these techniques are fraught with many drawbacks.
Recently, Neural Network Controllers (NNCs) are gaining popularity in modeling, identification and control power electronic converters. These controllers are advanced controllers and having fast dynamic behaviour and robustness.

In this paper, neural network controller design of soft switched half bridge (SSHB) dc/dc converter is discussed in detail. The performance of half bridge converter with neural network controller is analyzed under steady state, transient region and dynamic region by considering the line voltage variation and duty ratio variation. The SSHB converter is implemented and simulated in MATLAB/Simulink. The simulated results are presented.

Keywords

Soft switched Half bridge converter, neural network controller, cascade controller, steady state analysis, dynamic analysis

1. INTRODUCTION

In this modern era of nanotechnology semiconductor devices such as; metal oxide semiconductor field effect transistors (MOSFETs), Insulated gate bipolar transistors (IGBTs), Insulated gate conduction thyristors (IGCTs), MOS controlled Thyristors (MCTs), Gate turn off thyristors (GTOs), MOS turn off thyristors (MTOs), Emitter turn off thyristors (ETOs) etc,have widen the applications of power electronic converters due to their high efficiency, high switching speed and low cost [1-4]. Nowadays, these converters are available in compact size and can with stand high voltage, high power and high frequency. SSHB converter is most advance type of dc/dc converter in which a half bridge converter is connected on primary side of the transformer. In previous research [5-6], an extended state space technique was used to model the half bridge converter. A new control scheme (i-e Turn off time control at DCM) for half bridge converter was also introduced to control its dynamics. Such control scheme operates in continuous conduction mode (CCM) at heavy loads while at light load SAB topology enters into discontinuous conduction mode (DCM). When this topology enters into DCM it generates oscillations in output voltage as well as inductor current [5-7]. These oscillations create disturbances and degrade the performance of converter. Furthermore, disturbances generated due to the conventional techniques leads to the generation of abnormal harmonics which have deleterious effects not only on the systems network but affects badly the performance of the converter and also have adverse effects on loads.

In previous works, the conventional PI regulators were used as feedback control techniques for half bridge converter. But control strategy design is fraught with some problems and is not giving desired results. These controllers have limitations in handling the nonlinear situations of the converters as reported by various researchers [2,7-10]. The PI controllers are generally based on linear functions and their control characteristics may fail during system variations. Further, these are optimal at some fixed operating conditions only but their performance may not be optimal under varying operating conditions.
By considering the shortfalls and limitations of PI controllers, particularly under nonlinear conditions, it is deemed that the neural network controller (NNC), being an advanced and reliable nonlinear controller, can readily improve overall efficiency and effectiveness of the SSHB converter, specially, in discrete and dynamic system networks.

2 SOFT SWITCHED HALF BRIDGE DC-DC CONVERTER

The soft switched half bridge converter is a buck derived topology operates in the step-down mode and the power is delivered from the source to the load. This converter topology has gained popularity because of its simple soft switching, simple controller designing as compared to other topologies, low volume and weight, and low cost due to less number of active and passive devices. The SSHB converter because of its above mentioned attractive features has wide industrial

applications such as; switch mode power supplies, dc motor derives, high voltage direct current (HVDC), wind farms etc.
The schematic diagram of SAB converter is shown in Figure 1 that is composed of half bridge inverter and an uncontrolled full wave rectifier. The dc supply voltage is converted into ac voltage with the aid of half bridge inverter and then ac voltage is again rectified by full wave rectifier. Both converters are isolated with high frequency transformer and two active switches are connected at primary side of the transformer. Because of two active switches, neither pulse width modulation nor phase shift control techniques are used in such converter. Therefore, a turn off time control technique is used to control the dynamics of converter [5-6].

The power of such topology is controlled with active switches. The power is transferred from primary to secondary of transformer. The output voltage of this converter is always less than supply voltage that's why such topology referred as buck derived topology. The SSHB converter is also soft switched topology. Soft-switched converters are 4th generation converters that combine the advantages of conventional PWM converters and resonant converters [3].
Soft switched techniques reduce the switching losses and stresses, therefore, soft-switched converters can be operated at high frequencies (typically 500 kHz to a few megahertz). Further, these converters also suppress the electromagnet interference (EMI).

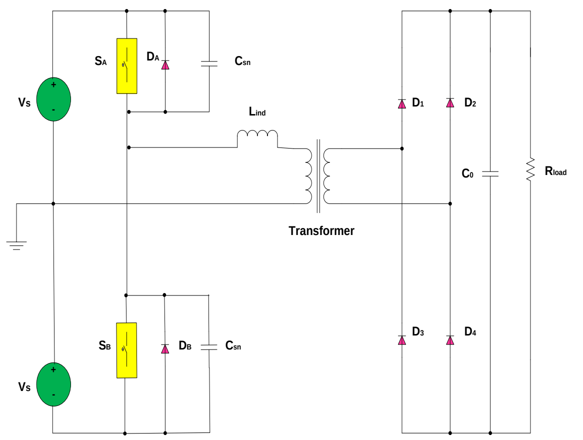

Fig 1: Circuit diagram of Soft switched half bridge dc/dc Converter

3 Artificial neural network

Artificial Neural Network (ANN) is a branch of soft computing which nowadays extensively used in many science and engineering disciplines to solve simple and complex problems. ANN is defined by various researchers [12-13], as "densely interconnected assemblies of adaptive simple processing elements, called neurons, units or nodes, whose functionality is loosely based on the biological neuron. The processing ability of the network is stored in the inter-unit connection strength, or weights, obtained by a process of adaptation to, or learning from a set of training patterns. Artificial Neural Network, also termed as Neurocomputing or Parallel Distributed Processes (PDP) or connectionist networks or simply neural networks".

Neural Network Controller recently gaining popularity because of its dynamic behaviour and robustness .The neural network controllers enhance the system performance, increase system speed and reduce the system complexity. They have also self adapting capabilities that make them able to control nonlinearities, uncertainties and parameter variations of the plant. The neural network enables parallel and distributed processes because of its parallel structure [2,7,12-17].

Nowadays neural network found various industrial applications such as robotics, temperature control, servo motor control, different chemical processes, vehicles control, aircraft controls, pattern recognition including character recognition, speech recognition, face recognition, on-line signature recognition colour recognition etc.Neural networks also used for process identification, failure detection, digital signal processing (DSP) architectures, underwater vehicle, Communication, medical applications etc [13, 18].

The artificial neural network can be classified into feed-forward neural networks and recurrent or feedback neural networks. Feed-forward neural network (FFNN) are either single layer or multilayer types. The neural network architecture describes the pattern of network, that is number of neurons and their interconnectivity. These neurons are connected in different layers and they operate in parallel. Each ANN architecture has its own learning rule. In this research work FFNN is used to control the dynamics of SSHB converter.

Figure 2 shows the feedforward neural network. It is simply layered with input layer, hidden layer and an output layer. The input layer of feedforward neural network consists of fan out elements only. This layer collects the data and fed to one or more hidden layers, where data is processed and finally readout at output layer. The selection of number of hidden layers and number of neurons in different layers depends upon the application.

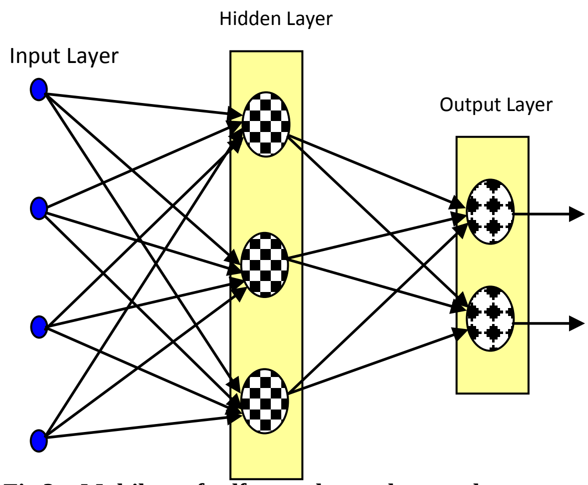

Fig 2: Multilayer feedforward neural network

This architecture of neural network is a most commonly used in power electronics converters since last couple of years because of enormous advantages [16-17]. It is simple to implement and allows supervising learning. When FNN receives signal, it transmit in the forward path only from one layer to next layer. It uses same activation functions in particular layer and in different layers it may use different transfer functions. For the training of this network mostly back propagation method is used [13-18].

4 DESIGN OF NEURAL NETWORK CONTROLLER FOR SSHB CONVERTER

The neural network designed for SSHB converter is based on cascade control scheme as are shown in Figure 3.

The cascade control scheme is based on two loops (i-e voltage and current loops). The output voltage of SSHB converter is used as feedback for outer voltage loop while inductor current is considered as feedback for inner current loop. Both current and voltage loops are designed with separate neural network controllers. The current loop is designed in such a way that it must be faster than voltage loop. The control scheme is designed with Multilayer Feedforward Neural Network (FNN). The architecture of FNN is constructed with input, hidden and output layers. The implementation of FNN architecture is simple and used back propagation algorithm for training.

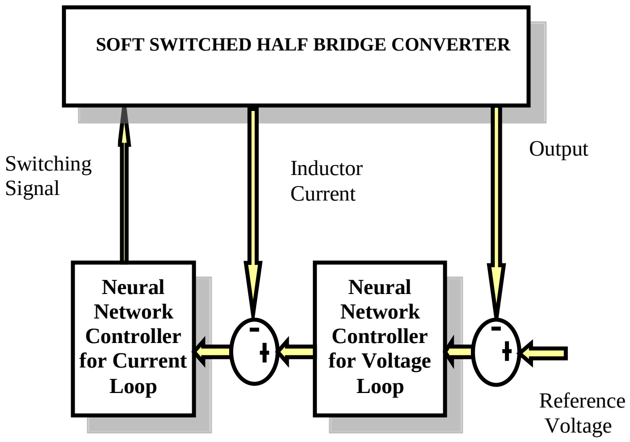

Fig 3: NNC based cascade scheme of SSHB topology

4.1 Training of NNC for SSHB converter

The design of neural network controllers is based on training data. The data for the design of NNC for voltage loop of SSHB converter is obtained from PI regulator during simulation. In the same way, current loop's data is achieved during the simulation of NNC for voltage loop and PI controller of current feedback loop. After several repeated training tests, the successful training was achieved on five neurons in single hidden layer for voltage loop and also single hidden layer consists on three neurons in single hidden layer are considered for current loop. The performance error during training for voltage loop NNC as illustrated in Figure 4, was achieved at 900 epochs. Similarly, performance error for current loop is shown in Figure 5.

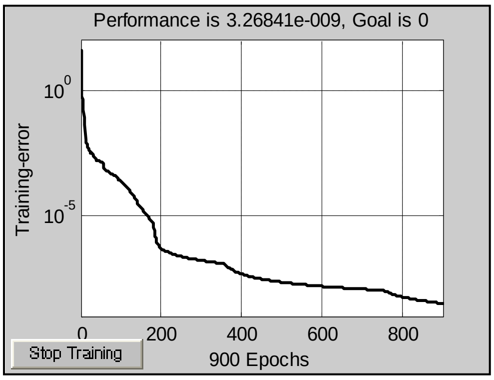

Fig 4: Performance error for voltage loop NNC

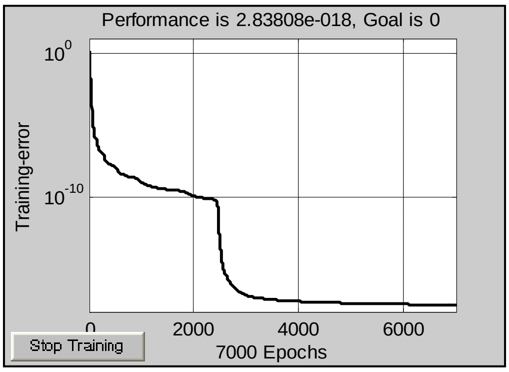

Fig 5: Performance error for current loop NNC

4.2 Design of neural network controllers for voltage and current loops

The NNC is designed for both voltage and current loops on the basis of weights and biases values obtained during training.

The simulink model of neural network controller for voltage loop is constructed with two inputs, five neurons in a single hidden layer and one neuron in the output layer. Such network is also referred as 2-5-1 network. The sigmoid activation function is used for each neuron of hidden layer and linear activation functions is used for output layers. The output voltage of SSHB converter is taken as feedback parameter for voltage loop. This feedback parameter is compared with reference value and comparison difference is applied to input port '1' of simlink model of voltage loop. The output port '2' of simulink model considered as reference value for NNC of current loop as illustrated in Figure 6.

Similarly, the NNC for current loop is designed on the basis of weights and biases values are achieved during training. It is layered with two inputs, three neurons in hidden layers and single neuron in output layer. This network is called 2-3-1 network. The sigmoid and linear activation functions are used for hidden and output layers respectively. The input of this controller is received the signal from the output of NNC for voltage loop. The output of this controller is used as switching signal and applied to power stage of SSHB converter.

4.3 Simulation model of SSHB converter with NN controllers

The complete Simulink block diagram of Neural Network Controller for soft switched half Bridge dc/dc converter is given in Figure 6. The SSHB converter controlled with two separate neural network controllers which are designed for inner current control loop and outer voltage control loop. The Neural Network controllers of the loops have been designed in such a way that the current loop is faster than the voltage loop. Such control structure referred as cascade control. The simulation model of the SSHB converter with neural network controllers is implemented in MATLAB/Simulink software.

The overall working of the SSHB converter model controlled with NN controllers is explained as under:

The output voltage and inductor current of SSHB converter, as indicated in Figure 6, are taken as feedback parameters. The output voltage (V_o) of SSHB converter is taken as feedback parameter and compared with reference voltage (V_{ref}). The comparison difference is applied as an input of NNC for voltage loop. The output of voltage loop NNC controller is taken as reference current of NNC controller for current loop. The inductor current (I_L) is taken as second feedback parameter and subtracted from the reference current. The output of the current controller is used as switching signal for solid state switches of the SSHB converter.

The power stage of SSHB converter, as shown in Figure 6, is developed from its state space model as given below. This model is a second order system, in which the inductor and capacitor are the state variables of the converter.

$$\begin{bmatrix}\dot{x}_1\\ \dot{x}_2\end{bmatrix} = \begin{bmatrix}0 & -\dfrac{1}{L_{ind}}\\ \dfrac{1}{C_o} & -\dfrac{1}{RC_o}\end{bmatrix}\begin{bmatrix}x_1\\ x_2\end{bmatrix} + \begin{bmatrix}\dfrac{2d-1}{L_{ind}}\\ 0\end{bmatrix} V_s$$

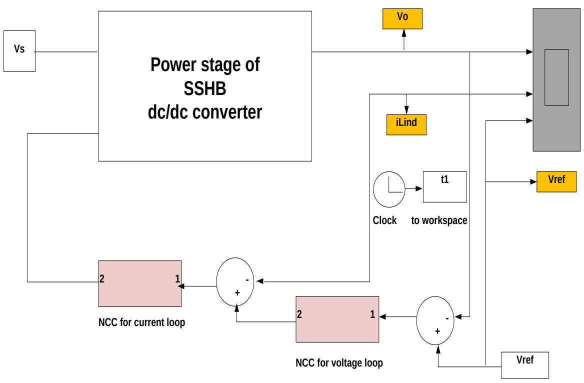

Fig 6: Simulation Block diagram of SSHB Converter with Neural Network Controllers

Parameters for the simulation of SSHB converter have been taken from [5-6] and are given in Table 1.

Table 1 SSHB Parameters

Parameter name	**Symbol**	**value**
Input supply	V_S	450 V
Output voltage	V_o	400 V
Inductor	L_{ind}	150mH
Output Capacitor	C_o	400µF
Snubber capacitor	C_{sn}	10 nF
Switching frequency	f_s	10 kHz

5. STEADY STATE ANALYSIS OF SSHB CONVERTER

The simulated results of inductor current and output voltage of SSHB converter under steady state operation are given in Figure 7 which shows the behaviour of inductor current and output voltage. SSHB converter controlled with NN controllers gives satisfactory results in steady state region. Both the output voltage and inductor current are free from oscillations. During this operation the output voltage is maintained by the controllers at 400 volts and inductor current at 5A.

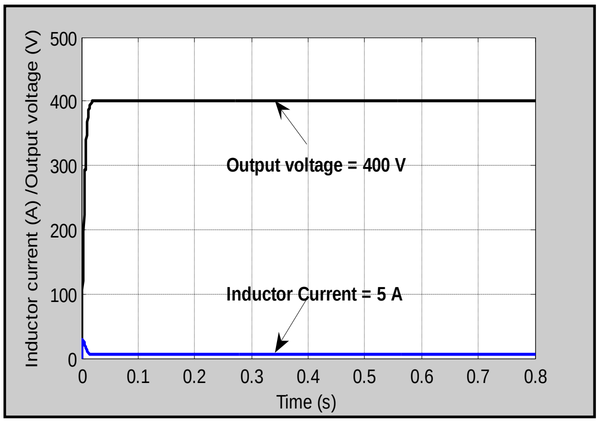

Fig 7: Waveforms of SAB converter during Steady-sate operation.

6. TRANSIENT ANALYSIS OF SSHB CONVERTER

Power electronic converters produce high starting current as well as overshoot in output voltage during their operations. The overshoots during starting decrease the overall performance of the converters. To minimize these oscillations different control techniques have been used. The behavior of SSHB dc/dc converter in transient region is also analyzed. The NN controllers minimized the starting current of SSHB converter. It is clear from the graph, as illustrated in Figure 8, the maximum overshoot in inductor current is approximately 24.47 A from its steady state value. The NN controllers successfully return backs the inductor current to its normal value after the time interval of 15 milliseconds.

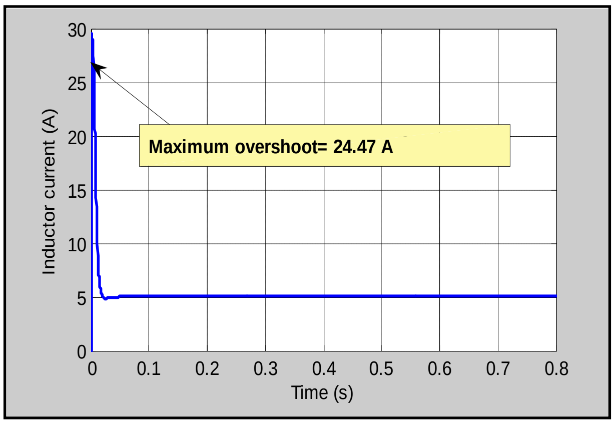

Fig 8: Transient Analysis of SAB Converter

The maximum overshoot in inductor current is approximately 26% less than pervious work of [5-6]. Similarly, the settling time of voltage and inductor current is 20 % less than the pervious work.

7. DYNAMIC ANALYSIS OF SSHB CONVERTER

The SSHB converter controlled with NN controllers are also analyzed under dynamic region by considering line and duty ratio variations.

7.1 Line Variations

The performance of SSHB converter is analyzed under line variations. A 50V, 300 Hz sinusoidal signal is given to observe the performance of converter. The simulated results of this converter under line variation is given in Figure 9. It is clear from waveforms, when converter is controlled with NNC controllers, the negligible oscillation in inductor current is produced which is reduced to 6 times as compared to previous work [5-6].

7.2 Duty Ratio Variations

Figure 10 indicates the simulated results waveforms of duty ratio variation. To check the performance of SSHB converter, the duty ratio variation signal as given in Figure 9 is applied and results of output voltage and inductor current is observed. It is clear from Figure 9, that the neural network controllers are well reduce the oscillations of the output voltage as well as inductor current. The SSHB converter with NNC has no oscillation in output voltage while oscillation is produced in output voltage, as mentioned in previous work, when same converter was controlled with PI controller. Similarly, the peak to peak overshoot in inductor current is 30 times reduced as compared to previous work as given in [5-6].

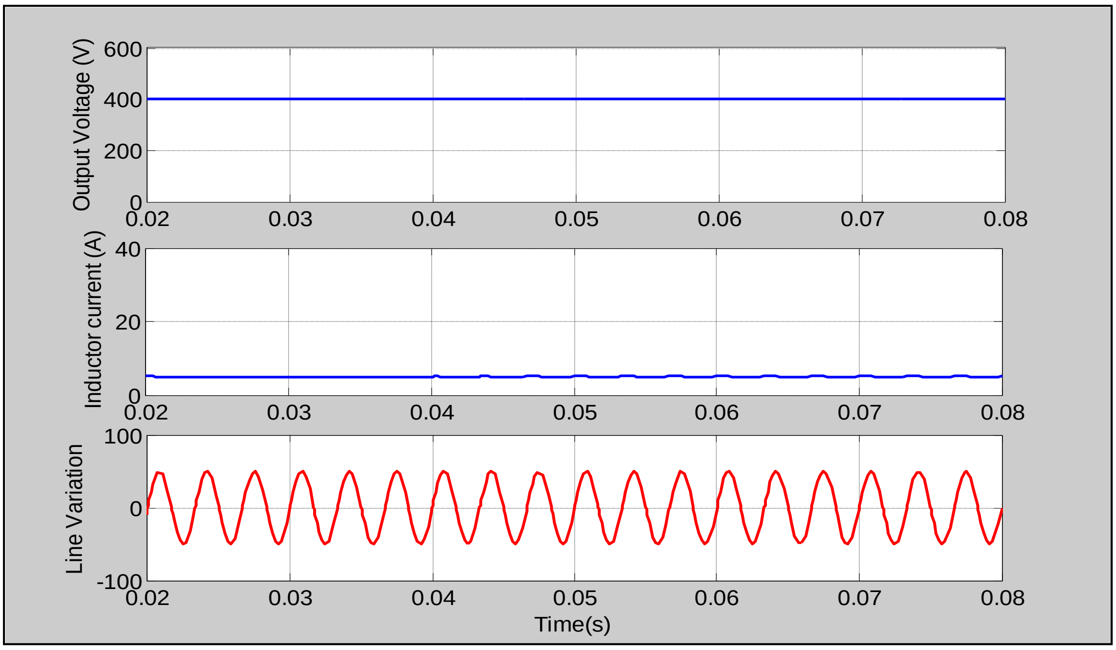

Fig: 9 Simulated waveforms of SSHB converter with NNC during Line variations

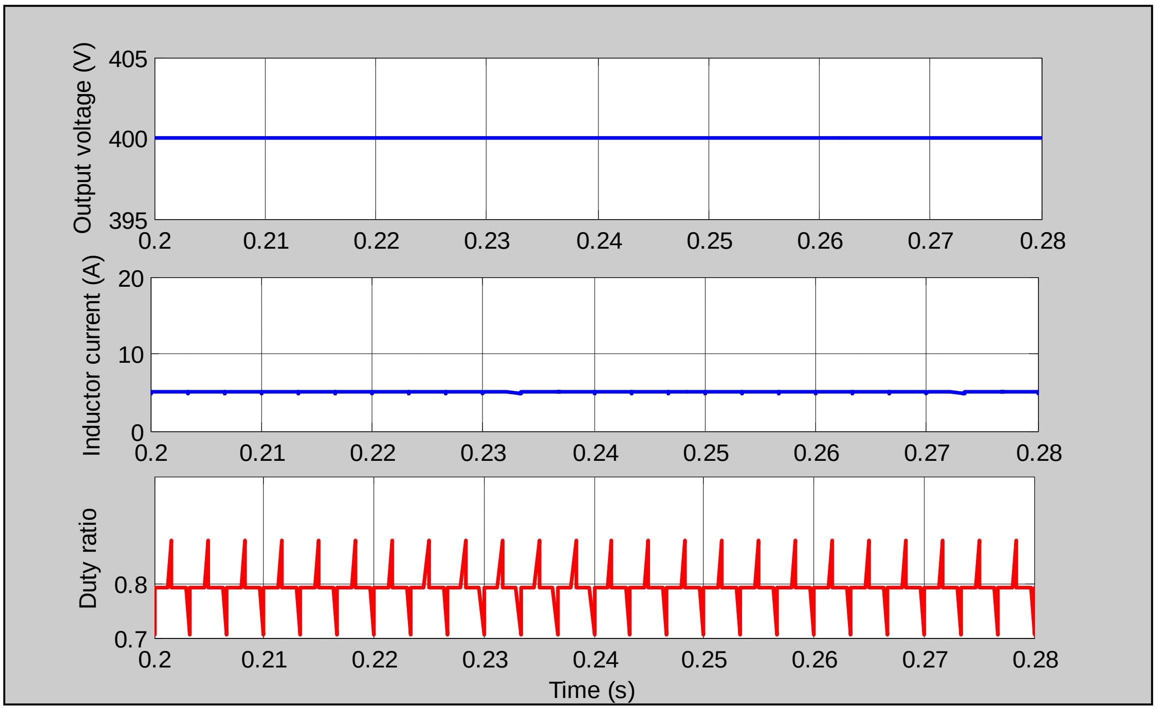

Fig: 10 Simulated waveforms of SSHB converter with NNC during duty ratio variations

8. COMPARISON RESULTS OF SSHB CONVERTER

The simulated results of soft switched half bridge converter controlled with NN controllers are compared with conventional PI controllers as used in pervious research work.

Figure 11 indicates the comparison results of inductor current of SSHB converter with NN controllers and PI controller of previous research. The results of SSHB converter with NN controllers under transient, reference voltage variation, duty ratio variation and line voltage variations cleary reflect that the performance of neural network controller is robust against nonlinear situations as compared to PI controller.

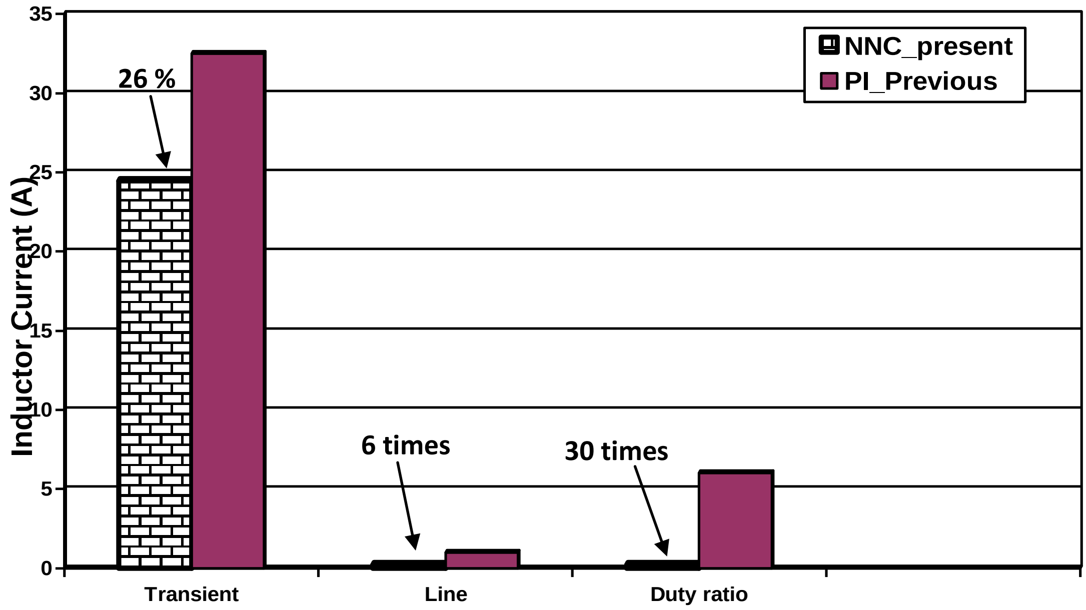

Fig: 11 Comparison results of inductor current of SAB converter

The simulated output voltage results as shown in Figure 12 of SSHB converter controlled with NNC is compared with previous research work. The Settling time of SSHB converter with NNC under transient region is 20 % reduced as compared to PI controller. This comparison of settling time of SSHB converter is illustrated in Figure 13.
It is clear from comparison results, the performance of SSHB converter controlled with NN controllers is much better than PI controllers under nonlinear situations.

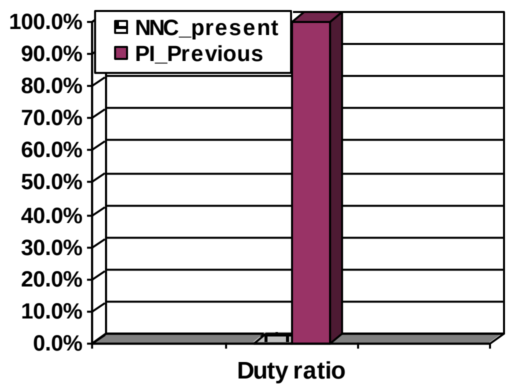

Fig 12: Comparison results of output voltage of SSHB converter

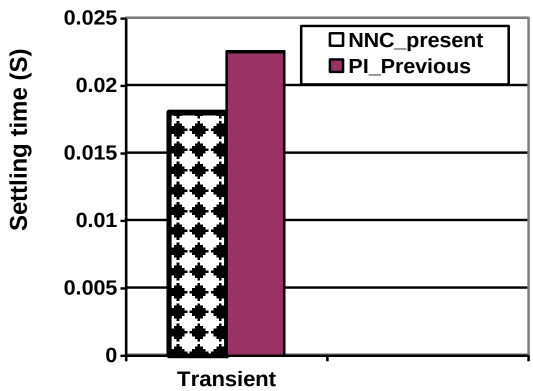

Fig 13: Comparison results of settling time of SSHB converter

9 CONCLUSIONS

In this research work, feed forward neural network controller is designed for SSHB converter and its performance under steady state, during starting, Transient region and dynamic region by considering the line variation and duty ratio variation is analyzed.
The cascade control scheme is a novel control scheme which is used first time in this research work for multi switch converters.
During steady state operation the performance of SSHB converter with NNC was tested. The output voltage is well regulated and no oscillation is produced.

The maximum overshoot in inductor current is approximately 26 % while settling time is about 20 % less than previous work when SSHB converter is controlled with NNC during transient region.

The NNC also well damped the oscillation of SSHB converter during line variations. No oscillations are produced in output voltage. The peak to peak oscillation in inductor current is 6 times less than previous work..

The output voltage of SSHB converter with NNC has no overshoot and peak to peak oscillation in inductor current is 30 times reduced as compared to previous work during duty ratio variation.

Analyzed results of the simulated SSHB converter model based on NNC clearly shows the robust and efficient performance of the neural network designed controller. This controller have well damped the oscillations in the output voltage as well as inductor current against nonlinear situations as compared to PI controllers as used in pervious research.

Thus, this controller has proved to be an advanced nonlinear controller having fast dynamic behaviour which improves the system performance.

10. ACKNOWLEDGEMENTS

The authors wish to acknowledge the Department of Electrical Engineering, Mehran University of Engineering and Technology Jamshoro, for providing all necessary facilities for the completion of this research work

11. REFERENCES

[1] Blaabjerg, F., Consoli, A., Ferreira, J.A., and Wyk J.D. 2005 'The future of electronic power processing and conversion' , IEEE Transaction on Power Electronics, Vol. 20, pp.715-720.

[2] Mahar M.A., Uqaili M.A, Larik A S, 2010 'Controller design of Buck dc dc Converter using Neural Networks' Mehran University Research Journal, Vol. 29, pp. 163-168.

[3] Rashid M. 2004 'Power Electronics circuits, devices and applications', 3rd editin, Pearson Education, Inc. Singapore

[4] Mahar M.A, Abro M.R, Larik A.S 2009 'Artificial Neural Network Control of Single-Active Bridge DC-DC Converter' Mehran University Research Journal Vol. 28, No.4, pp:591-598.

[5] Demetriades, G.D and Nee H.P, 2008 'Small signal analysis of the half bridge soft switching unidirectional converter employing extended state space averaging', IEEE Power Electronics and Motion Control Conference, 2008, pp.385-391.

[6] Demetriades G.D and Nee H.P, 2005 'Characterization of the soft-switched single-active bridge topology employing a novel control scheme for high-power dc-dc applications', IEEE, 36th Power Electronics Specialists Conference 2005, pp.1947-1951.

[7] Mahar, M.A. Larik, A.S. Abro, M.R. Uqaiki M.A, Unar. M.A and Shaikh A.R. 2012, "Wind Power Performance Improvements Using Artificial Neural Network Controller for DC–DC Converter" Energy, Environment and Sustainable Development, Springer-Verlag/Wein.

[8] Mahar, M.A. Abro, M.R. and Larik, A.S. 2009'Simulation Analysis of Cascaded Controller for Buck dc dc Converter' Mehran University Research Journal, Vol. 28, , pp.349-356**.**

[9] Mohammad, A; M. Kuisma.; P. Silventoinen. 2004 'Comparison between PID Control and Sliding Mode Control for Buck Converter, Proceedings of the Symposium on Power Electronics', Electrical Drives, Automation and Motion. SPEEDAM 2004. CAPRI – ITALY.

[10] Tsang, K. M.; and Chan, W. L. 2008 'Non-linear Cascade Control of DC/DC Buck Converter' ,Electric Power Components and Systems, Vol. 3, pp.977 — 989.

[11] Larik A S, Abro M R, Unar M A and Mahar M A. 2008 'A novel approach for the control of dual active bridge dc dc converter', CCIS Springer Berlin Heidelberg, Vol. 20, pp.343-349.

[12] Basheer, I.A. and Hajmeer, M. 2000 'Artificial neural networks: fundamentals, computing, design, and application', Journal of Microbiological Methods, Vol. 43, pp. 3–31.

[13] Haykin S. 1999, 'Neural Networks: a comprehensive foundation', 2nd edition, Pearson Education, Inc., Singapore.

[14] Bose, B.K. 2001 'Artificial Neural network applications in power electronics', IECON'01: The 27th annual conference of the IEEE industrial electronics society.

[15] Bastos, J.L., Figueroa, H.P., and Monti, A. 2006 'FPGA Implementation of Neural Network-Based Controllers for Power Electronics Applications', Applied Power Electronics Conference and Exposition, 2006. APEC '06. Twenty-First Annual conference of IEEE, pp.1443-1448.

[16] Chun, F.H. 2009 'Design of intelligent power controller for DC–DC converters using CMAC neural network', Neural Computation & Application, Vol. 18, pp.93–103, United Kingdom.

[17] Marsala, G.; Pucci, M.; Vitale, G.; Cirrincione, M.; and Miraoui, A. 2009 'A prototype of a fuel cell PEM emulator based on a buck converter', Science Direct journal of Applied Energy, Vol. 86, pp.2192–2203.

[18] Zilouchian, A.; and Jamshidi, M. 2001 'Intelligent control systems using soft computing methodologies', CRC Press, USA